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RESEARCH ARTICLE

Assess the annual effective dose and contribute to risk of lung cancer caused by internal radon 222 in 22 regions of Tehran, Iran using geographic information system

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Abstract

Radon gas is one of the most influential sources of indoor exposure. All its physical properties together make it a significant risk factor for lung cancer in the population. The research aims are outlined as (1) to measure the radon concentration in Tehran city and compare results with the international standards (2) to determine spatial distribution of radon gas concentration using Geographical Information System (GIS) software and (3) to estimate the annual effective dose and potential risk of lung cancer by radon-222 in Tehran city. In this study, 800 Alpha Track detectors were installed in houses in 22 regions of Tehran city and retrieved after 3 months. The measurements were repeated for spring and summer and autumn seasons. The annual effective dose and risk of lung cancer were assessed using standard equations. Data were analyzed using SPSS 20. Result showed the minimum and maximum radon concentration were observed in and Ghalee-kobra (0.13 Bq.m^{-3}) and Charbagh-ponak district (661.11 Bq.m^{-3}) respectively. There was no observed relationship between radon concentration and houses' model, cracking condition and constructionn materials. Expectedly, the storehouses and basements had significantly higher ($P = 0.016$) radon concentration than occupied rooms. The min and max of the estimated annual effective dose were 0.65 and 2.03 mSv, respectively. Result showed that around 5% of the sampling sites had higher level of radon than the maximum allowed by EPA. A rough estimation of the expected radon-attributed lung cancer incidences yielded approximately 5958 cases in the total population of Tehran every year. In view of the growing trend in cancer incidences, appropriate measures addressing radon should be undertaken in areas of increased exposure to this noble gas.

Keywords Radon 222 · Risk · Lung cancer · Tehran · Iran

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Introduction

Radon is an odorless and colorless gas which belongs to the noble gas family. All of its known isotopes are unstable. The most long-living and abundant isotope, radon-222, has a half-life of 3.82 days. Radon-222 is an intermediate decay product of uranium-238, thorium-233 and uranium-23, which are the primary sources of indoor radon found in soil, rocks, drinking water, construction materials and natural gas [1, 2]. The greatest exposure of human to radon occurs in residential homes [3, 4]. Typically for houses, the radon gas is coming from a few sources. Mainly, the radon emanation comes from soil and crustal stones in the substructure of buildings [5–7]. Depending on the geology of the area, the amount of radon input varies from house to house. Construction materials are another source of indoor radon in buildings. It is estimated that

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the radon from these materials accounts for the increase in dose rate of radon by 30 to 50% [8–11]. Becquerel per cubic meter is the SI-recommended unit for measuring levels of radon in the air [12]. World Health Organization (WHO) suggested reference level of 100 Bq m^{-3} to minimize health effects due to indoor 222Rn inhalation [13]. At the same time, the permissible limit proposed by the US Environmental Protection Agency (EPA) is 148 Bq.m-3. If the concentration of radon exceeds 148 Bq.m-3, specific precautionary actions are required. Further preventive measures should be carried, when the radon level exceeds 296 Bq.m-3 [14, 15].

In 2000, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported that radon-222 contributes 1.0 mSv to the average annual effective dose from natural radioactive sources, which is about 2.4 mSv. Although radon has less impact on human health outdoors its accumulation in confined spaces such as homes, mines and work environments can pose additional health risk [16–18]. Exposure of residents to high concentrations of indoor radon over a long period of time contributes to functional respiratory effects as well as increases the risk of lung cancer, [16–19] About 3–20% of the total deaths from lung cancer attributed to long-term exposures to radon inhalation in closed spaces [7, 20]. Key studies in Europe, North America, India and China confirmed that radon is a significant risk factor of lung cancer in human populations [21–23]. Although, many studies have been carried out to measure the level of radon-222 in Iran [24–26], the information about effective dose and corresponding risk of lung cancer in Iran and namely in Tehran city is scarce. The purposes of this research were [1] to evaluate the concentration of radon gas and compared with EPA standard [2] to determine spatial distribution of concentration of radon gas using Geographical Information System (GIS) software [3] to use the measurements to approximate the annual effective dose and contribute risk of lung cancer caused by radon-222 in Tehran city.

Material and methods

Geology of study area

The research was carried out in 22 regions of Tehran city, Iran. Tehran is located at 35° 41′ 39.80“ N and 51° 25’ 17.44” E. Its height varies from free water level is 1800 m north to 1200 m in the center and 1050 m in the south [27–29], Tehran is spread across two mountain valleys and a desert on the southern slopes of the Alborz Mountains. [Fig. 1] The main feature of Tehran’s geology is its location between the Alborz Mountains and the Iranian plateau, which is associated with the existence of active faults such as Mosha-Fasham fault, North Tehran fault, and the Rey fault, which caused mild and subtle earthquakes in the area. These faults can increase the radon concentration on the surface of the earth. The data regarding the concentration of radon gas were collected by Air Pollution Control Company, which is the company related to

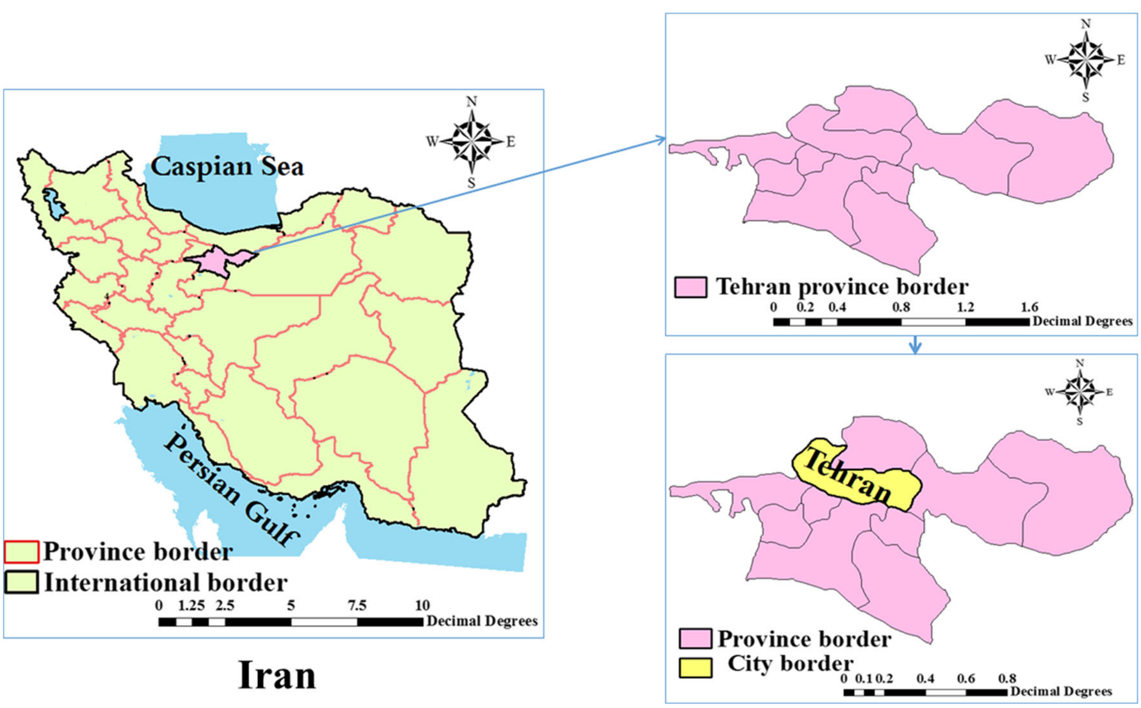

Fig. 1 Location of Tehran in the geography of Iran

Tehran municipality. In this cross-sectional study 800 dosimeters were located in confined spaces at 680 m from each other around the whole area of Tehran City [27–34]. Fig. 2.

Measuring the radon concentration

Radon concentration was measured via Alpha Track method. The Alpha Track detector was purchased from Track Analysis Systems TASL Ltd. In the beginning, the detectors were covered in aluminum foil in order to be protected from environmental damages. Detectors inside houses, according to the Environmental Protection Agency (EPA) protocol, were exposed for at least 3 months to measure the long-term radon concentration [27, 28, 30, 31]. As well the detectors were located at a height of 50 to 90 cm above the ground, away from the window and sunlight, for the same period, according to EPA standards. [Fig. 3] [28, 35] Also, the features of homes such as their approximate age, height above ground level, cracks in walls, floor, ceiling, and the type of material used in homes was recorded on a checklist. In order to evaluate the effect of measuring season, radon concentration was measured in spring, summer and autumn. To comply with the ethical rules, for each house, the consent form was already filled out by the homeowner.

Solid-state nuclear track detectors (SSNTDs)

SSNTD detectors are one of the best methods for temporal measuring of radon gas due to their rigidity and ease of use. Moisture and low temperatures do not change the accuracy of measurements. Due to the inherent quality of the materials used in the detector, it does not require any source of energy to record alpha particles. [3, 30, 36] These sensors placed in the air of the environment detect the radon-induced alpha particles, then are developed by the electrochemical method and then visualized and counted using a microscope [28, 36].

Detectors reading

After 3 months, the detectors were transferred to the monitoring center of Mazandaran University of medical sciences to assess the concentration of radon. In the next step, CR-39 detectors were exposed to a 6.25 M sodium hydroxide solution at 85 °C for 3 hrs. Indoor radon concentration was calculated by determining the abundance of traces of alpha particles. Calibration and determining the calibration coefficient were obtained by the radiation protection unit of the Atomic Energy Organization of Iran. The calibration samples were exposed with 107/285 kBq by RN-1025 radium source, transmitter flux model, referring to the US NIST Laboratory, according to PYLON's No. 1001611 certificate.

Determine the annual effective doses

The average annual effective dose (mSv) of the residents of Tehran, caused by indoor radon concentration air, was determined using the following eq. (1): [37].

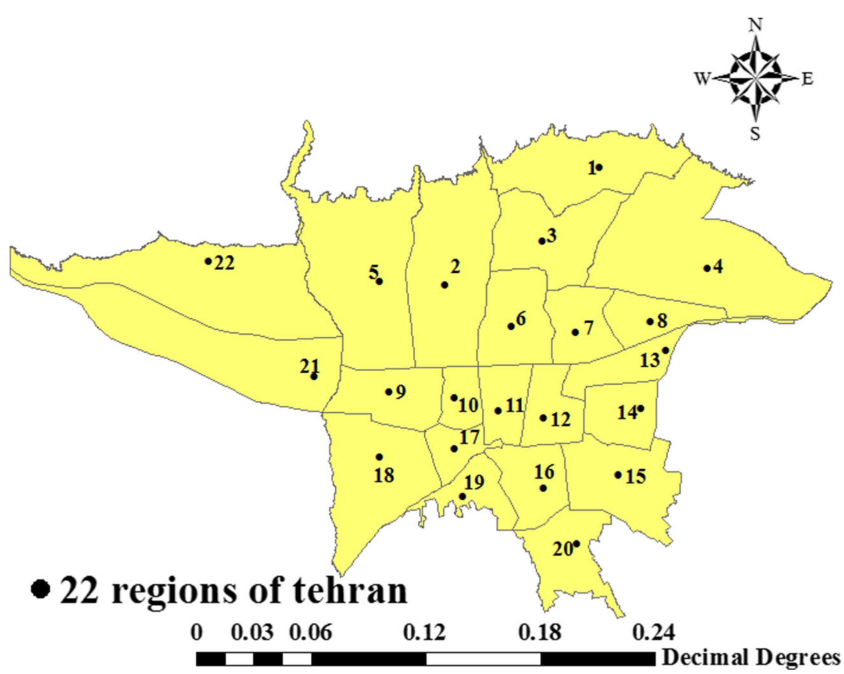

Fig. 2 Sampling points of Tehran regions for measured concentration of radon 222

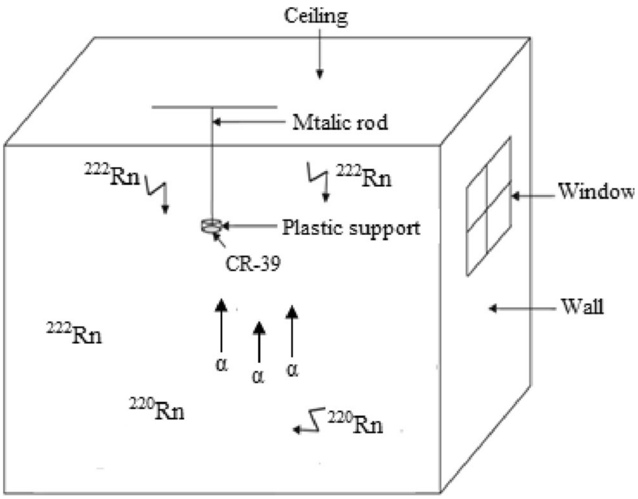

Fig. 3 Schematic representation of the Alpha Track Detector with CR-39 film placed inside a house in accordance with the EPA guidelines

$$\mathrm{Ein} = \mathrm{CRn} \times \mathrm{F} \times \mathrm{H} \times \mathrm{T} \times \mathrm{D} \quad (1)$$

Where:

C is radon concentration (Bq.m-3).

F is the equilibrium factor which is equal to 0.4 for measurement of indoor radon concentration.

H is occupancy factor which is 0.8 for measurement of indoor radon concentration.

T is duration of occupation for 1 year that is roughly equal to 8760 hrs.

Occupancy factor is equal to the amount of person's attendance per year in the desired location in terms of the number of hours per year (h·y-1).

D is the conversion factor for radon dose which is equal to 0.9 [mSv·(Bq·h)-1·m3)].

Assessing the potential risk of lung cancer due to radon exposure

The potential risk of lung cbancer describes the expected incidences that can be attributed to inhalation of radon gas [1, 37]. Herein, the expected annual incidence of lung cancer cases per million people (Ilc) caused by radiation dose from radon-222 was determined by eq. (2): [37].

$$\mathrm{Ilc} = \mathrm{ERn} \times 18 \quad (2)$$

Where ERn = radon-222 effective dose.

ArcGIS

This study investigated the radon concentration using geostatistical methods in Tehran (Iran) using ArcGIS 10.1. Information on spatial diversity and the level of concentration is important for the management of indoor air pollution. One of the most suitable software for this purpose is GIS. An important aspect of GIS is that it simplifies the information used and makes the real world easier. In this research, in order to better understand the changes of pollutant concentration this software (ArcGIS 10.1) was used.

Statistical method

Mean, standard deviation, median and range were obtained using SPSS 20. To compare the means, t-test and ANOVA were used with a 0.95 confidence interval.

Results

The mean, minimum and maximum of concentrations of radon-222 in 22 regions of Tehran city are shown in Table 2. The overall maximum, mean and minimum of radon concentration were 661.11, 54.11 and 0.13 Bq.m-3, respectively (Fig. 5). The maximum radon concentration was observed in Charbagh-ponak district. The minimum radon concentration was observed in Ghalee-kobra. The effective dose and the annual lung cancer in 22 regions of Tehran city are demonstrated in Table 2. The maximum and minimum of annual effective dose were 2.03 and 0.65 mSv, respectively. The mean ± SE of annual effective dose was 1.23 ± 0.67 mSv. The expected annual risk of lung cancer in all regions was estimated at 487.44 cases per million people. The population of Tehran is about 12,223,598 people. Therefore, the total number of lung cancer incidences related to radon exposure is expected to be approximately 5958 cases in the total population of Tehran every year (Table 2). Fig. 4.

Relationship between constructions' features and the radon concentration

The relationship between radon concentration and the constructions' age

In the present study the constructions were classified into 3 groups: under 10 years old, 10 to 20 years old, and above 20 years old. The frequency of each category and the concentration of radon is shown on the Table 1. Data were analyzed using Kruskal–Wallis one-way analysis of variance. There was little to no significant relationship between constructions' age and radon construction ($P = 0.718$).

The relationship between radon concentration and construction model, construction cracking and construction's materials used in floor and ceiling

The proportion of apartment and villa checked houses, cracking and construction's materials are shown respectably in

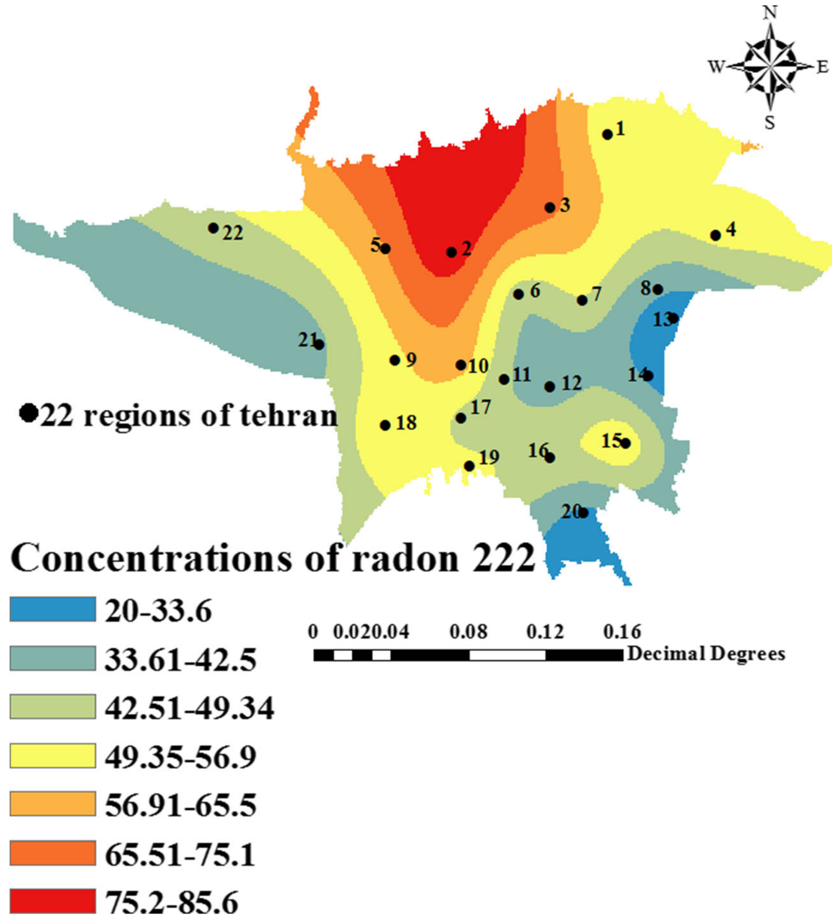

Fig. 4 Radon concentration (Bq.m) annual mean in the in 22 regions of Tehran city, Iran

Table 1. There was no observed relationship between radon concentration and houses' model, construction model, construction cracking and construction's materials based on Mann–Whitney test and Kruskal–Wallis one-way analysis of variance ($P = 0.737$), ($P = 0.514$) and ($P = 0.237$).

The relationship between radon concentration and place of dosimeter

In this study, the dosimeters were placed in bedroom, living room and storehouse. The radon concentration and frequency

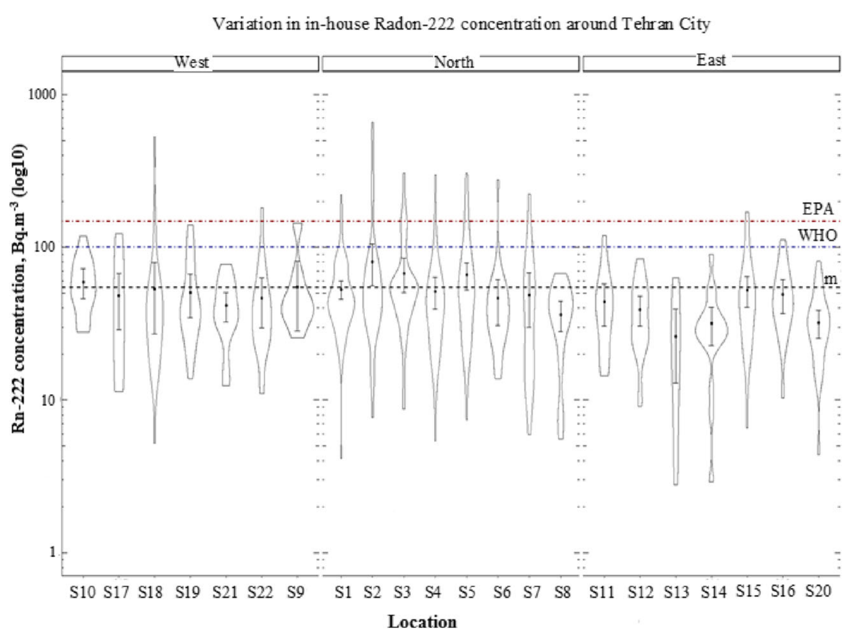

Fig. 5 Violin plots depicting variation in Rn-222 concentration around municipal regions of Tehran city, arbitrarily grouped by their geographical position and proximity to the geological faults. Within-group mean and confidence intervals are shown error as bars. Black dashed line (m) shows overall average. Dot-and-dash lines are reference values, demonstrating maximum radon concentration allowed by the Environmental Protection Agency (EPA, red) and the World Health Organization (WHO, blue)

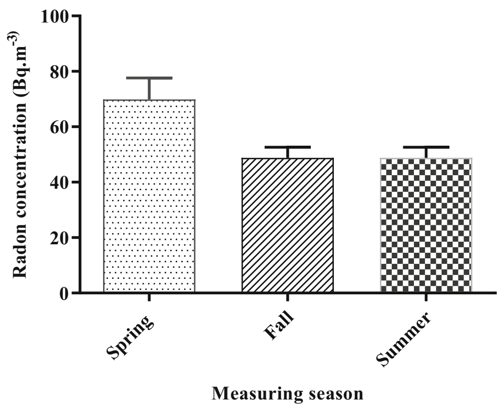

Fig. 6 Comparison of mean ± SE of radon concentration in spring, fall and summer

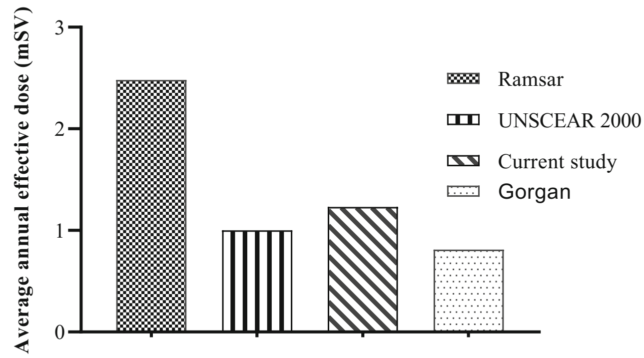

Fig. 8 Average annual effective dose due to radon-222 in Tehran city estimated in this study in comparison with that in other studies in Iran, and overall effective dose reported by UNSCEAR (2000) [16, 46, 56]

of dosimeters in each place are shown in Table 1. Although, there wasn't any relationship between concentration of radon and the location of dosimeters placed in the bedroom and sitting room. But, there is a significant relationship between the concentration of radon and the location of dosimeters placed in the bedroom and the storage room based on Kruskal–Wallis one-way analysis of variance ($P = 0.016$).

Relationship between radon concentration and season type

Radon concentrations were measured for thrice for 3 months in the consecutive seasons of spring, summer and autumn. There was a notable variation between radon concentration in spring and radon concentration in summer and fall based on Kruskal–Wallis one-way analysis of variance ($P < 0.05$) (Fig. 6).

Discussion

The presented study reports data on indoor concentration of radon-222 in 22 districts of Tehran city. Our results demonstrate that the indoor concentration of radon in most houses of Tehran was less than 148 Bq/m3 maximum level allowed by the EPA standards (4 pCi/l), and below the WHO allowed levels (100 Bq/m3) as well (Figs. 7 and 8). [12, 14] The radon concentration in Tehran city was reported 80 Bq/m3 by M. Sohrabi in 1988 [39]. Our results show lower levels than those measured before, which can be explained by differences in measurement method, measurement season, the number of samples. In Sohrabi et al., the number of sampled territories was 206 that is less than the number of sites reported in our study. The studied sites in the presented report where geographically different from those in the study by Sohrabi et al., as well. 11.4% of the investigated places were classified as "within caution' limits", i.e. between 74 and 148 Bq.m-3. Although, the radon concentration did not exceed the threshold, the precautionary actions should anyway be undertaken in order to decrease the radon concentration in the houses. In the current study, about 5% of all studied sites had Rn-222 concentration higher than EPA-allowed standard. Other research also reported that the same sampling areas had radon levels above the cautionary threshold [40–42]. There was a significant relationship between radon concentration in spring and radon concentration in summer and fall ($P < 0.05$). In contrast to summer and spring, in the autumn the air has less exchange inside homes because the windows and doors are closed. In Greece, a study was reported that maximum radon concentration was measured in the winter. Also, in this study the minimum radon concentration was found in the spring [43]. In addition, two research teams from Pakistan confirm that radon concentrations in winter tend to be higher than in summer [35, 44].

There is an uncertainty in published data on the relationship between age of buildings and indoor radon concentration. For example, Steele (2006) reported that there was no significant relationship between radon concentration and construction age [45]. On the other hand, radon concentration in older

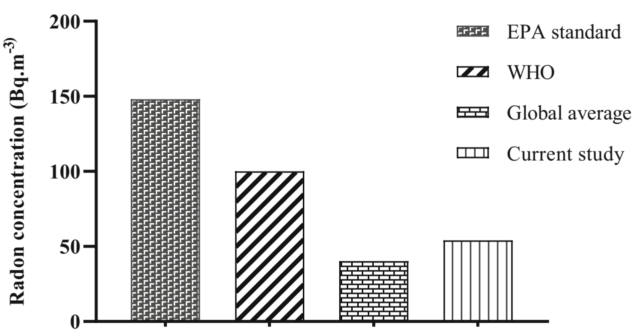

Fig. 7 Comparison of radon concentration measured in Tehran city with the maximum allowed values by EPA and WHO standards, and the global average [13, 14, 38]

Table 1 The relationship between radon concentration and parameters investigated

Parameter Construction's age	Frequency (%)	Mean radon concentration (Bq.m-3)	*P* value
Less than 10 years old	35	56.25	(P = 0.718)
10 to 20 years old	33.6	55.33	
Above 20 years old	31.4	51.57	
Construction model			
Villa	26.5	50.46	(P = 0.737)
Apartment	73.5	55.52	
Cracking position			
With cracking	40	56.90	(P = 0.514)
Without cracking	60	52.35	
Type of materials used in floor			
Ceramic	43	57.18	(P = 0.237)
Stone	20.1	52.88	
Mosaic	25.3	52.9	
Cement	6.9	42.56	
Parquet	4.7	59.74	
Type of materials used in the ceiling			
Cement blocks	9.4	64.71	(P = 0.237)
Brick	51.8	57.08	
Stone	5.1	45.43	
Concrete	21.1	47.48	
Ceramic	3.5	37.22	
Plaster	8.1	46.92	
Others	1	60.85	
Frequency of dosimeters in each place			(P = 0.016)
bedroom	26.1	44.31	
living room	18.4	53.65	
storehouse	55.5	59.49	
Frequency of windows' structure			
Single-walled window	40.5	57.71	(*P* = 0.874)
Double-glazed window	34.1	51.88	
Sealed windows	18.2	55.62	
Windows with vents	7.1	43.90	
Frequency of type of ventilation system			
Hood	70.5	53.74	(*P* = 0.425)
Ventilator	21.5	52.94	
Without Ventilator and hood	8	64.20	

houses in Romania was once reported higher than in modern ones [46]. The relationship between age of the construction and indoor radon concentration was not observed in our study. The results of our analysis correspond to the data from Naddafi et al. that was also collected in Iran [47]. The relationship between radon concentration and construction materials depends on the type of stone used in the construction materials. The overall result is that presence of granite contributes to radon build-up inside a building [38, 48]. Shoeib and his colleagues reported that radon concentrations in granite, cement stone and ceramics are higher than other houses' materials [37]. In our study, the radon dosimeters were placed in sitting room, bedroom and storeroom. There was a positive relationship between radon concentration in storeroom and bedroom, but no relationship was found between other rooms. Height and depth might be two important factors in measurement of the radon concentration in houses. The level of radon concentration will be generally lower in the houses with higher ceilings [49, 50]. Several factors can determine the amount of radon concentration in different classes, including air conditioning type, type of construction materials, and height of homes. Therefore, there is no fixed trend or formula to estimate radon concentration just by decreasing or increasing of height in houses [51]. Shaikh and his colleagues reported that the amount of radon concentration in first and nineteenth floors of an apartment house were 59 and 12.4 Bq.m-3

Table 2 Estimates of radon concentration, effective dose and the expected annual incidence of lung cancer in 22 counties of Tehran city

Municipal regions	N	^{222}Rn concentration (Bq m^{-3}) M ± SE [Min; Max]	Effective dose (mSv) M ± SE	Expected incidence of lung cancer per million people per year
1	75	52.93 ± 3.83 [4.16; 220.67]	1.33 ± 0.096	23.94
2	80	80.51 ± 12.55 [7.67; 661.11]	2.03 ± 0.31	36.54
3	41	67.51 ± 8.80 [8.71; 304.27]	1.70 ± 0.22	30.60
4	67	51.52 ± 6.31 [0.26; 297.70]	1.29 ± 0.15	23.22
5	71	65.81 ± 6.79 [7.41; 306.41]	1.66 ± 0.17	29.88
6	33	46.23 ± 7.79 [13.72; 276.06]	1.16 ± 0.19	20.88
7	25	48.82 ± 9.62 [5.92; 223.08]	1.23 ± 0.24	22.14
8	19	36.20 ± 4.17 [5.53; 67.54]	0.91 ± 0.10	16.38
9	8	54.84 ± 13.47 [25.61; 144.17]	1.38 ± 0.33	24.84
10	14	59.28 ± 6.72 [27.76; 117.98]	1.49 ± 0.16	26.82
11	16	43.98 ± 6.80 [14.37; 119.47]	1.10 ± 0.17	19.80
12	21	39.10 ± 4.39 [9.10; 83.72]	0.98 ± 0.11	17.64
13	10	26.01 ± 6.70 [2.80; 63.25]	0.65 ± 0.16	11.70
14	18	31.62 ± 4.53 [2.93; 89.51]	0.79 ± 0.11	14.22
15	38	52.40 ± 6.17 [6.57; 170.30]	1.32 ± 0.15	23.76
16	17	49.08 ± 6.21 [10.34; 111.93]	1.23 ± 0.15	22.14
17	15	48.05 ± 9.76 [11.38; 122.53]	1.21 ± 0.24	21.78
18	39	53.36 ± 13.39 [5.20; 529.88]	1.34 ± 0.33	24.12
19	18	50.63 ± 8.16 [13.72; 140.27]	1.27 ± 0.20	22.86
20	29	31.90 ± 3.36 [0.13; 80.80]	0.80 ± 0.08	14.40
21	17	41.36 ± 4.58 [12.48; 77.42]	1.04 ± 0.11	18.72
22	20	46.45 ± 8.46 [10.99; 181.48]	1.17 ± 0.21	21.06

in Mumbai, India [52]. The reason for reducing the amount of radon concentration can be related to an increase in altitude from the source of radon i.e. soil [53]. The result of a study indicated that the air conditioning system could significantly reduce radon concentration [54]. In our study, there was no a significant correlation between the air conditioning system and radon concentration, which was expected to exist. Therefore, more research is needed to be done in Tehran city to ensure that air conditioner system doesn't have a significant relationship with radon concentration.

Effective dose has a direct relationship with radon concentration. With the increase of the radon concentration, the effective dose also, obviously, increases. The average annual effective dose estimated in this study is a bit greater than indicated in the UNSCEAR report (2000) [16]. Although several factors can affect radon concentration in an area, the possible reason for such a contrast can be some earth faults in both Ramsar and Tehran. Many studies have shown that in areas where there were more geological faults, the annual effective dose was relatively high [55–57]. A study concluded that radon concentrations in areas that are closer and further than earth's crust faults are 115 and 20 kBq.m-3, respectively [58].

Conclusion

The potential annual incidence rate of lung cancer was estimated at approximately 5958 cases per year in the total population of Tehran. We confirm the previously reported data that only 5% of the Tehran area is characterized by levels of radon that exceed the EPA allowed maximum, which could be a significant factor promoting lung cancer. Geological features such as faults in the earth's crust, the height and depth of the sampling sites, the type of soil in the studied areas should be considered in the future radon measurements. Reconstruction and renovation of old houses, monitoring the insulation of buildings, Installation of ventilation systems, the non-use of building materials that have high radioactivity of radon 222 such as granite materials, and monitoring of construction by experts in radiation protection can reduce the risk of radon-induced lung diseases in Tehran's population. In conclusion, given that radon is the second leading cause of lung cancer in the world, indispensable measures should be taken in the areas where radon concentrations are higher than global standards.

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Compliance with ethical standards

Conflict of interest The authors of this article declare that they have no conflict of interests.

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